A Hydrologic Ensemble Seasonal Forecast System over the Eastern U.S.

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NOAA HDL/NCEP

Outline

- Background and relevance of the east-side hydrologic forecast system to NOAA's climate mission.
- U.S. east-side hydrologic forecast system
  - Initial strategy, implementation and evaluation
  - Expansion of the forecast domain
  - New multi-model approach under development
  - Issues related to seasonal predictability and forecast skill
- Summary and proposed expanded collaboration with NOAA

Background to the Eastern U.S. prediction activities

Builds on earlier NOAA-supported projects

- NLDAS: Development of a Hydrologically-Based Land Data Assimilation System for the Continental U.S.
- Land Surface Predictability Studies at GFDL

Current project's main science question

To what extent are seasonal climate predictions sufficiently skillful to improve hydrologic forecasts and water management decisions, and can this be demonstrated over the Eastern United States?

Predictions and Projections Objectives

(NOAA Climate Program Plan FY 07 - 11: C. Koblinsky)

Develop a predictive understanding of the global climate system on timescales of weeks to decades with quantified uncertainties sufficient for making informed decisions

- Improve intraseasonal and interannual **climate predictions** to enable regional and national managers to better plan for the impacts of climate variability and change
- Provide improved regional, national, and international **climate assessments and projections** to support policy decisions with objective information.

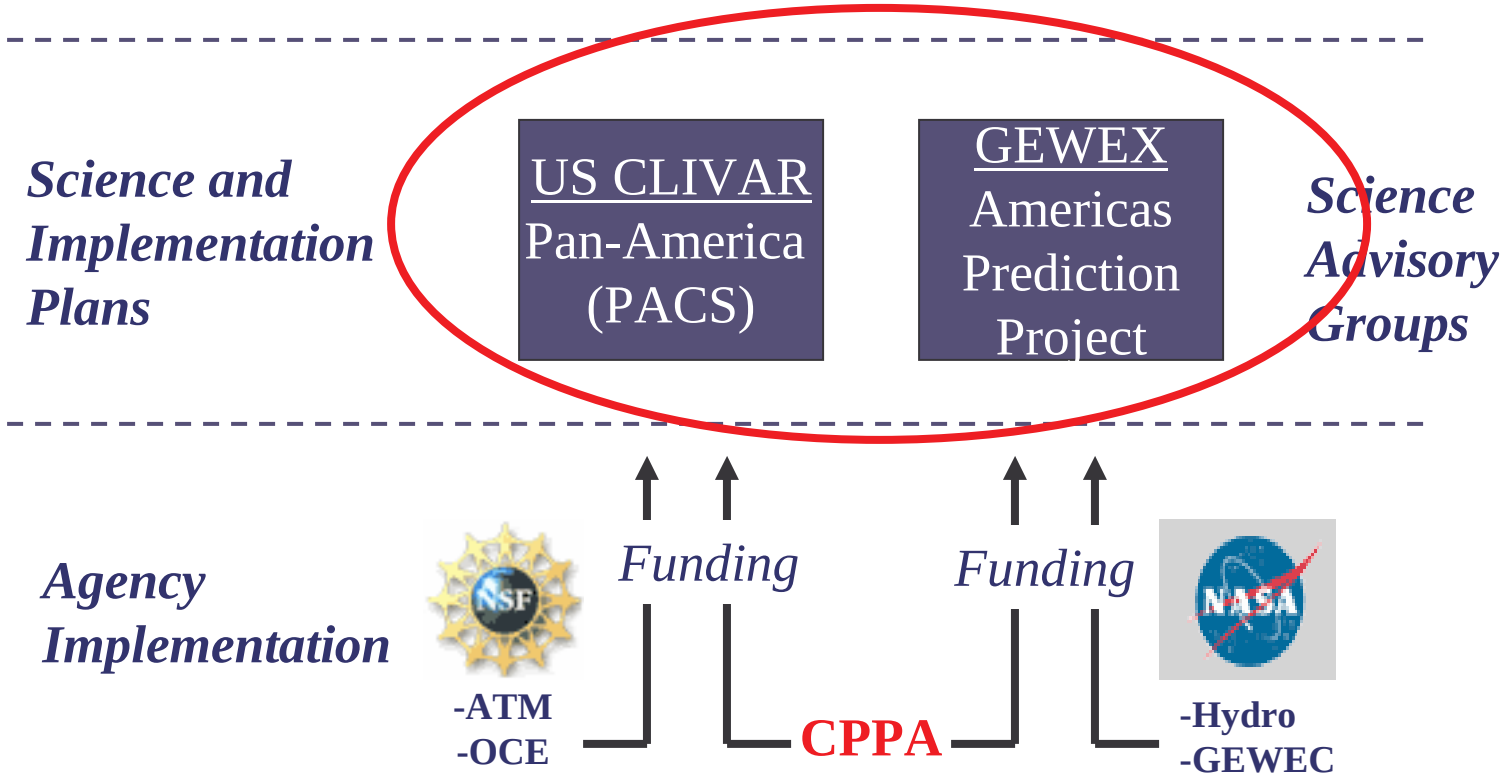
Desired End-State: A seamless suite of forecasts (e.g. outlooks and projections) on intraseasonal, seasonal, interannual, and multi-decadal timescales and applications using ensembles of multiple climate models in support of the mission outcome "*a predictive understanding of the global climate system*":

FY07: Provide regional resolution forecasts to decision makers through increased computer and model capacity.

FY11: Provide a broader suite of climate forecast products and services through development of Earth System Model.

NOAA OGP/CPPA Programmatic Structure

WCRP COPES (Coordinated Observations and Predictions of the Earth System)



CPPA goal is to improve intraseasonal-interannual climate forecasts and to interpret climate forecasts for better water resource management.

Background to the Eastern U.S. prediction activities

Three detailed scientific issues for the current project.

1. *Forecast uncertainty*

   What are the statistical properties of seasonal climate forecasts, and how does these relate to hydrologic forecast uncertainty?

   How does resulting forecasting skill depend on catchment size?

   What is the relative role of seasonal climate forecasts versus initial hydrologic conditions as they affect hydrologic forecast skill in the eastern U.S.?

2. *Removing seasonal climate model biases*

   Are there alternative methods to remove seasonal climate model biases in precipitation and temperature?

   To what extent can multi-model forecasts lead to lower hydrologic forecast uncertainty?

Background to the Eastern U.S. prediction activities

Three detailed scientific issues for the current project.

3. *Generating hydrologic ensemble predictions*

   How can uncertainties in hydrologic models, model parameters and hydrologic initial conditions be best represented?

   How can hydrologic ensemble forecasts be verified, and can the forecasts be used reliably and, if so, over what forecast periods?

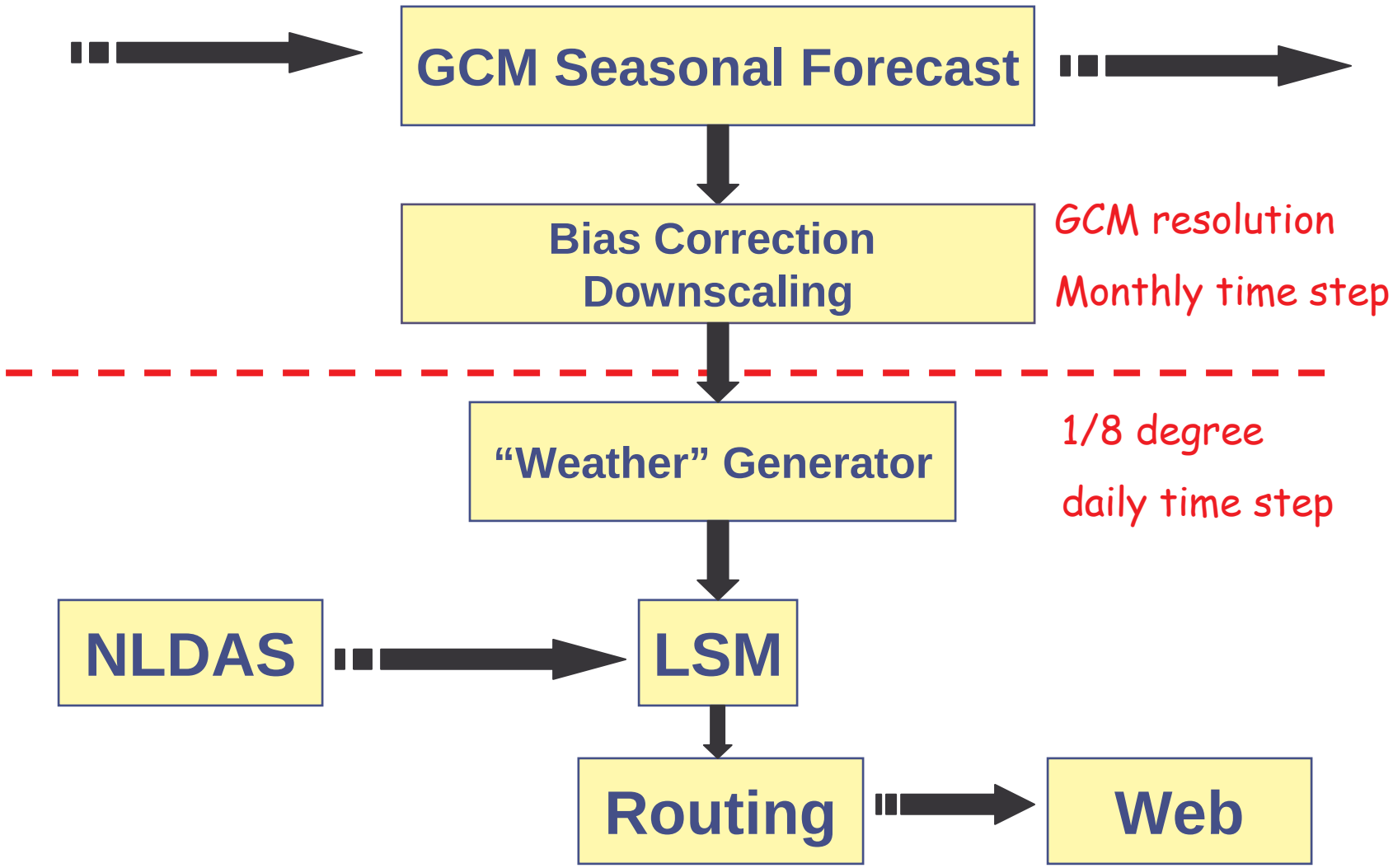
US East-side Seasonal Hydrologic Forecast System

2003: Started development of the Ohio Basin seasonal hydrologic forecast system.

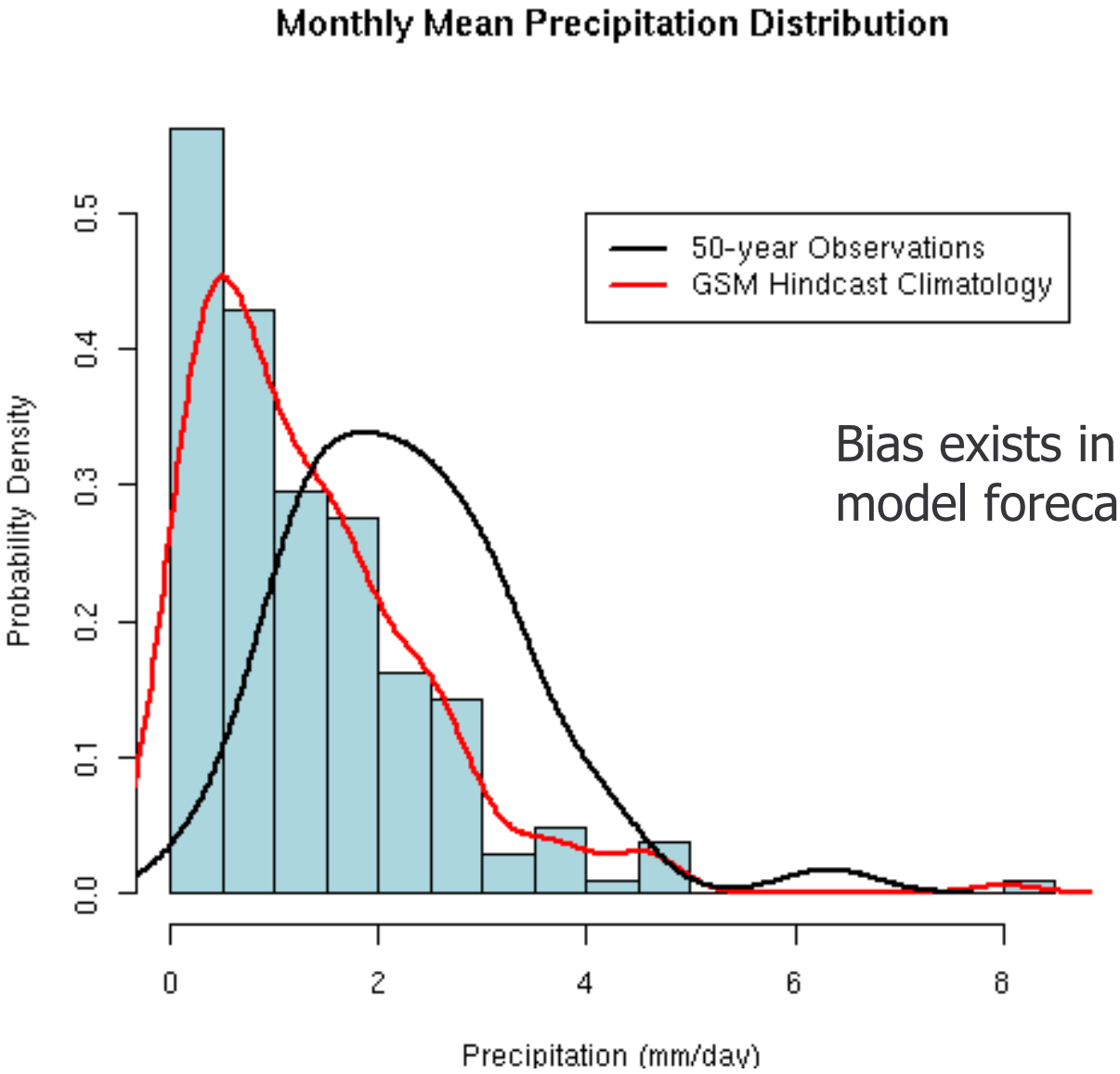
Approach.

1. GSM and NSIPP forecast are used in the seasonal forecast period.
2. Bias correction and downscaling approach same as the Western U.S. system utilizing the UW 50-yr NLDAS retrospective data sets. Corrected at GCM grids and transferred to 1/8th degree.
3. Initial conditions are created using real-time NLDAS forcing running at daily time step (Tmin, Tmax, Precipitation)
4. Day-to-day progression of T and P are taken from historical data, and P scaled to match monthly total precipitation.

US East-side Seasonal Hydrologic Forecast System

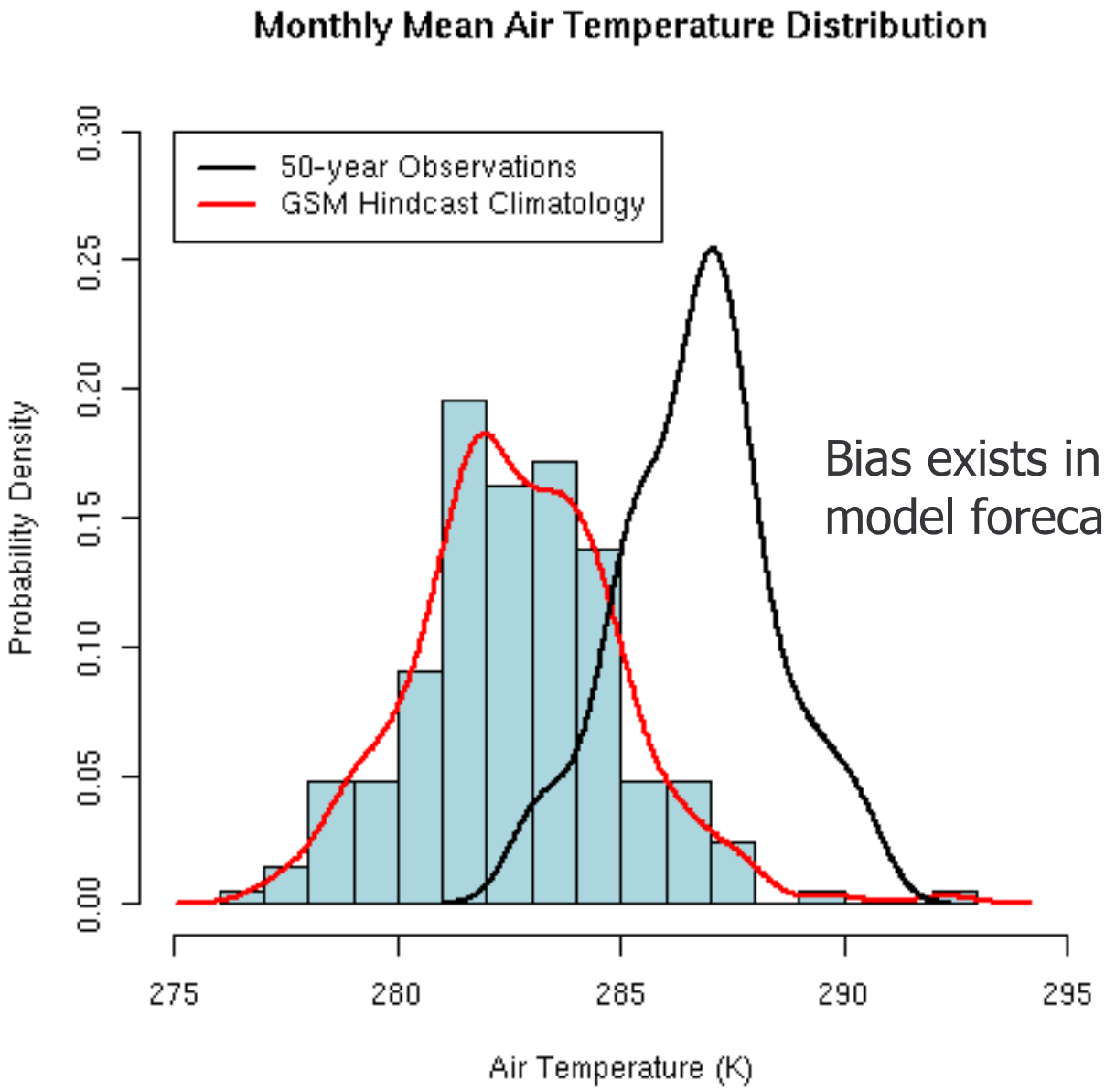


GCM Forcing Bias – Precip.



Bias exists in climate model forecast

GCM Forcing Bias – Air Temp.



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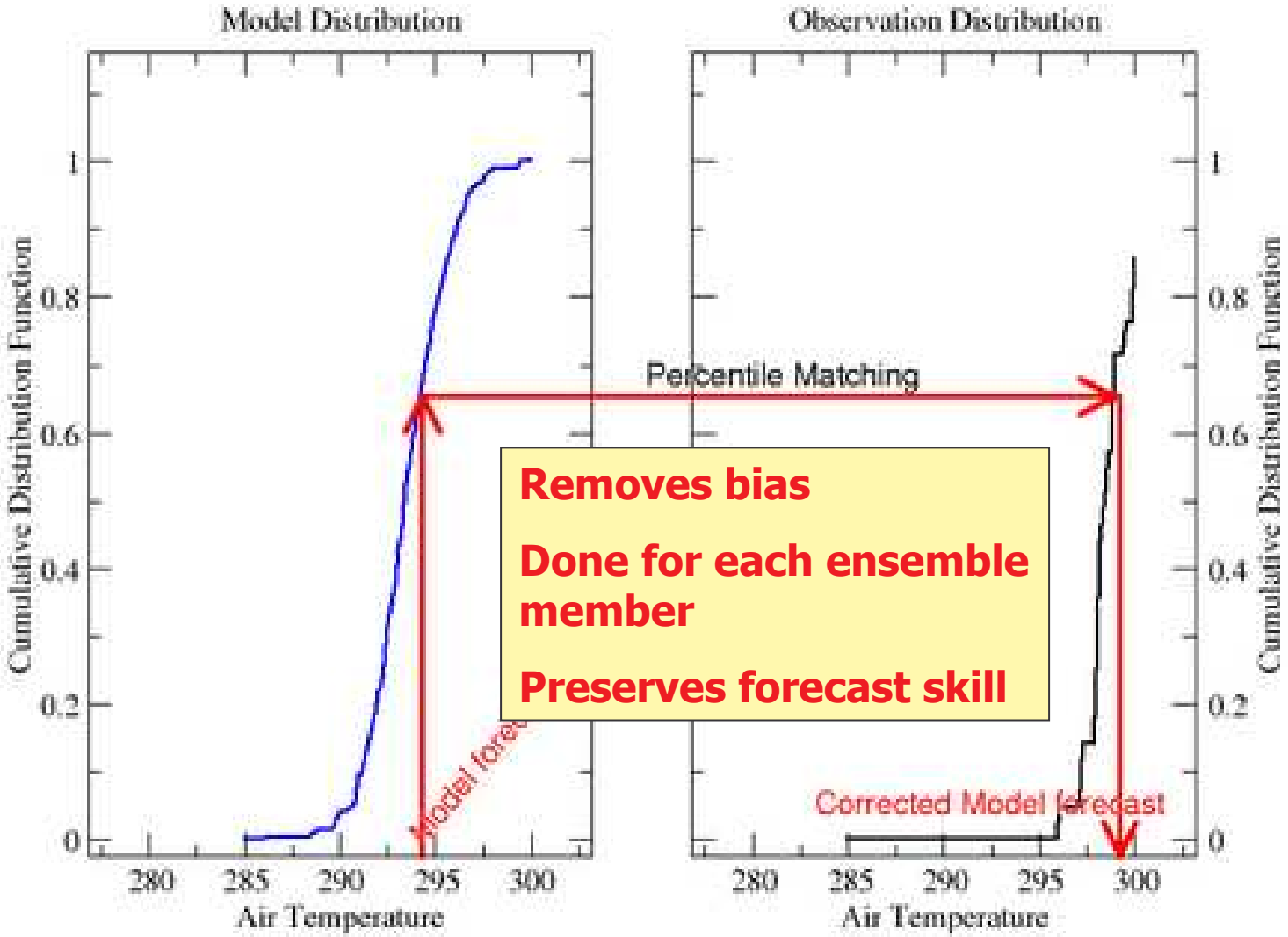
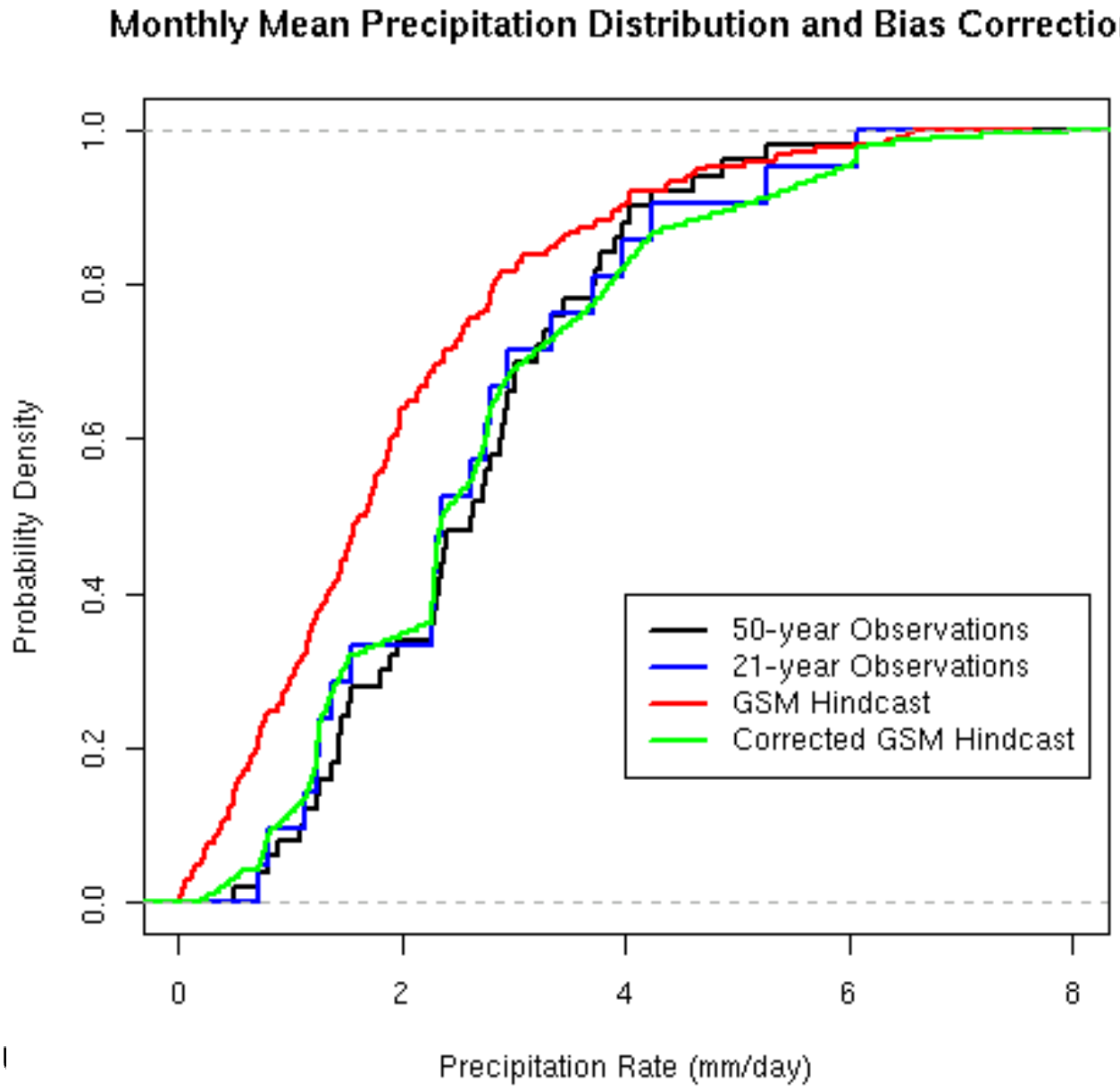
Bias Correction: Probability Mapping



Corrected Forcing – Precipitation



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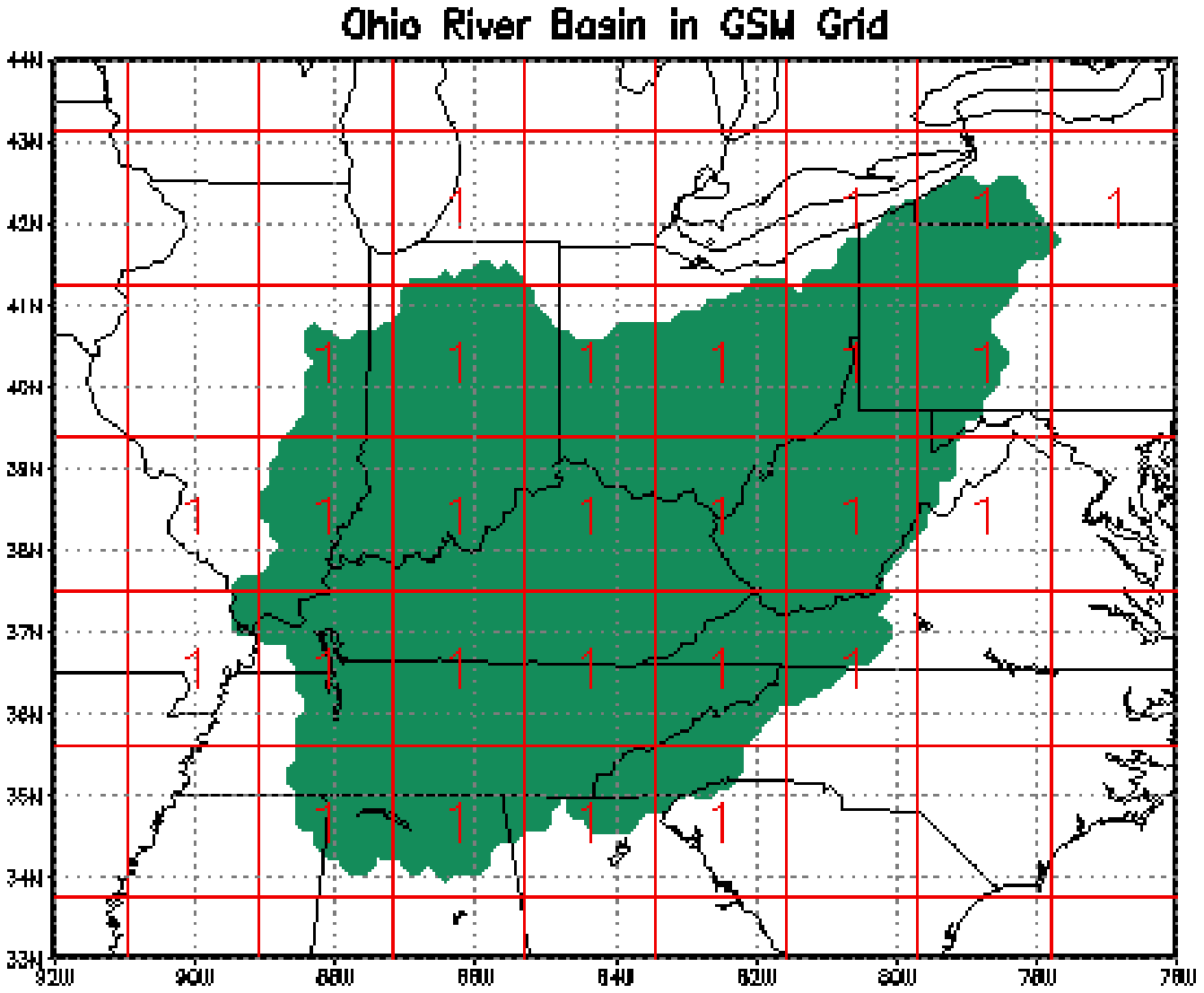
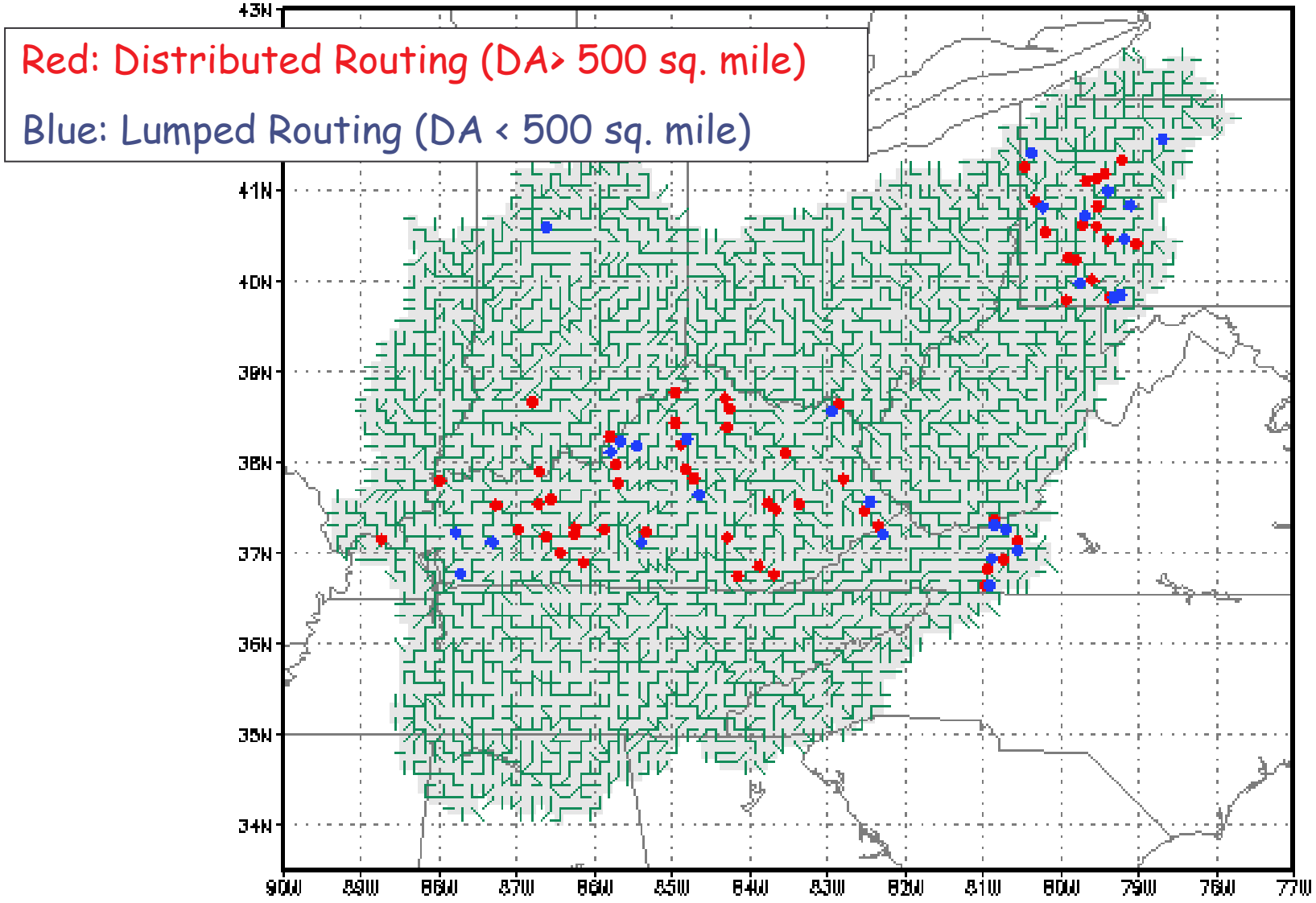
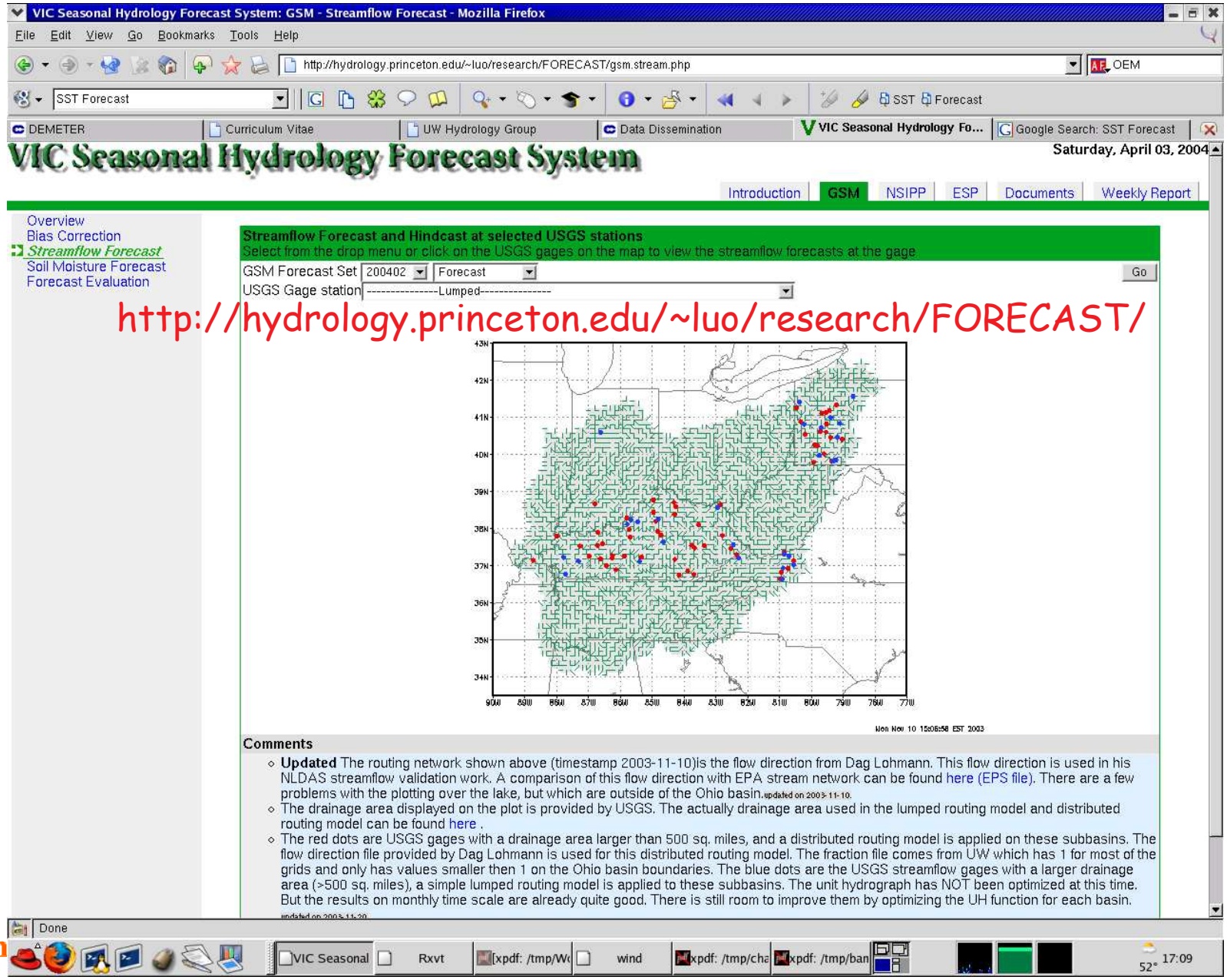
Downscaling



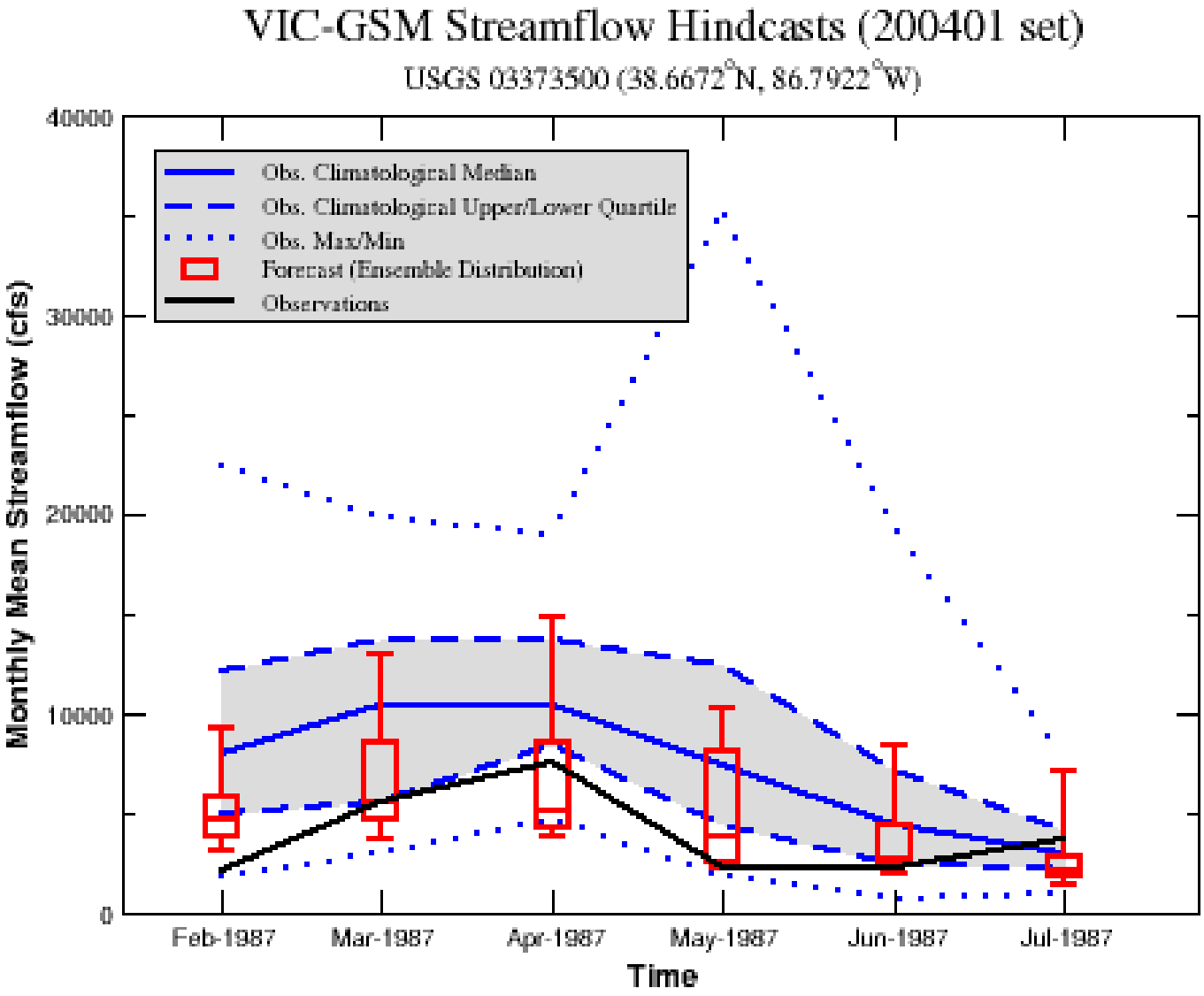
USGS Streamflow Stations over Ohio River Basin



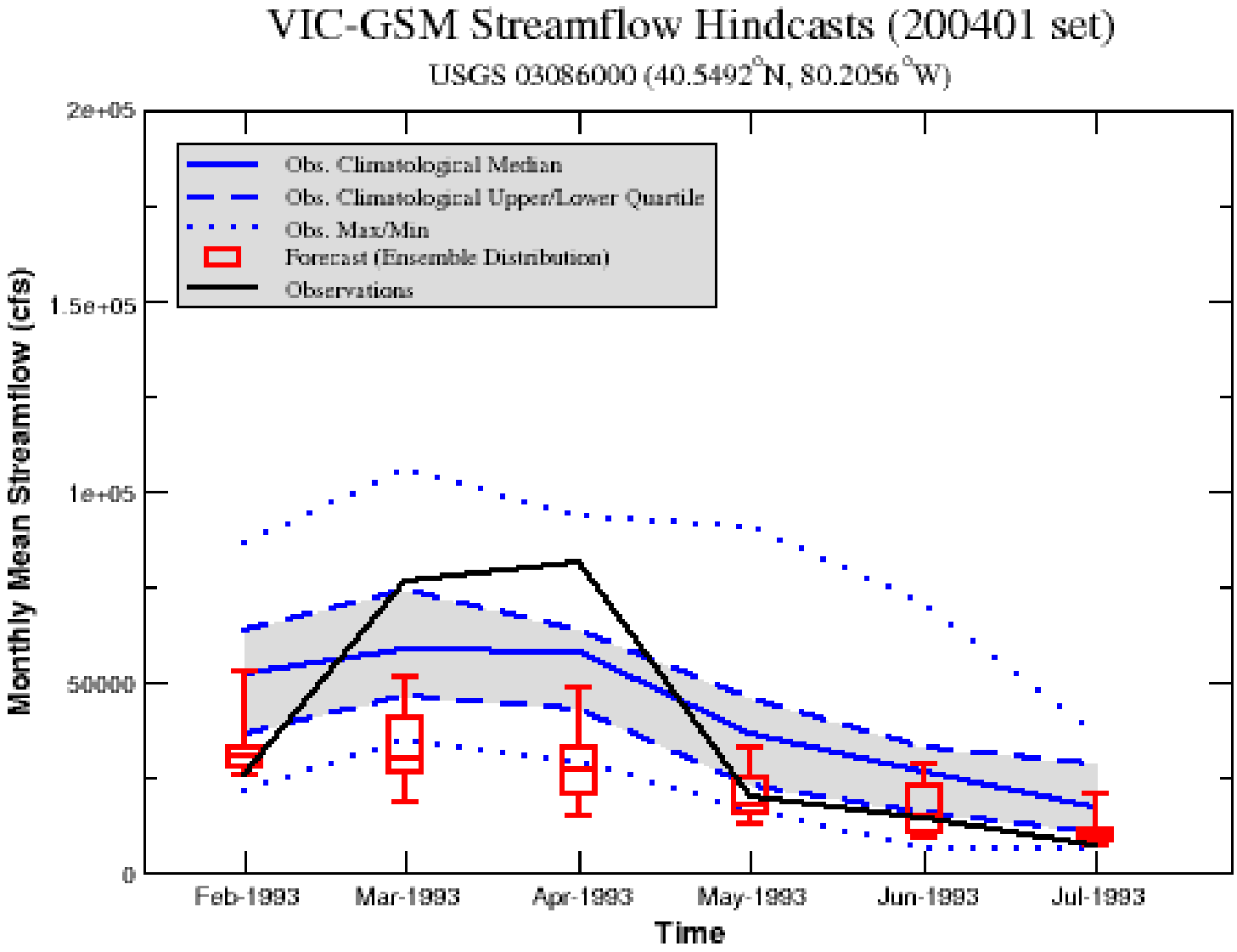
Web Interface



Hindcast Evaluation (Example 1)



Hindcast Evaluation (Example 2)



Problems with the Initial Implementation

The overall forecast skill in the Ohio is quite low.

- Bias correction scheme performs well.
- VIC and the routing model have errors, but they can be calibrated and are not a major error source.
- The transfer of GCM monthly precipitation to 1/8 degree daily precipitation (spatial downscaling and weather generator) is one source of uncertainty and errors.
- The major problem is lack of skill in the GCM seasonal forecasts.

Current Status of Our Forecast System

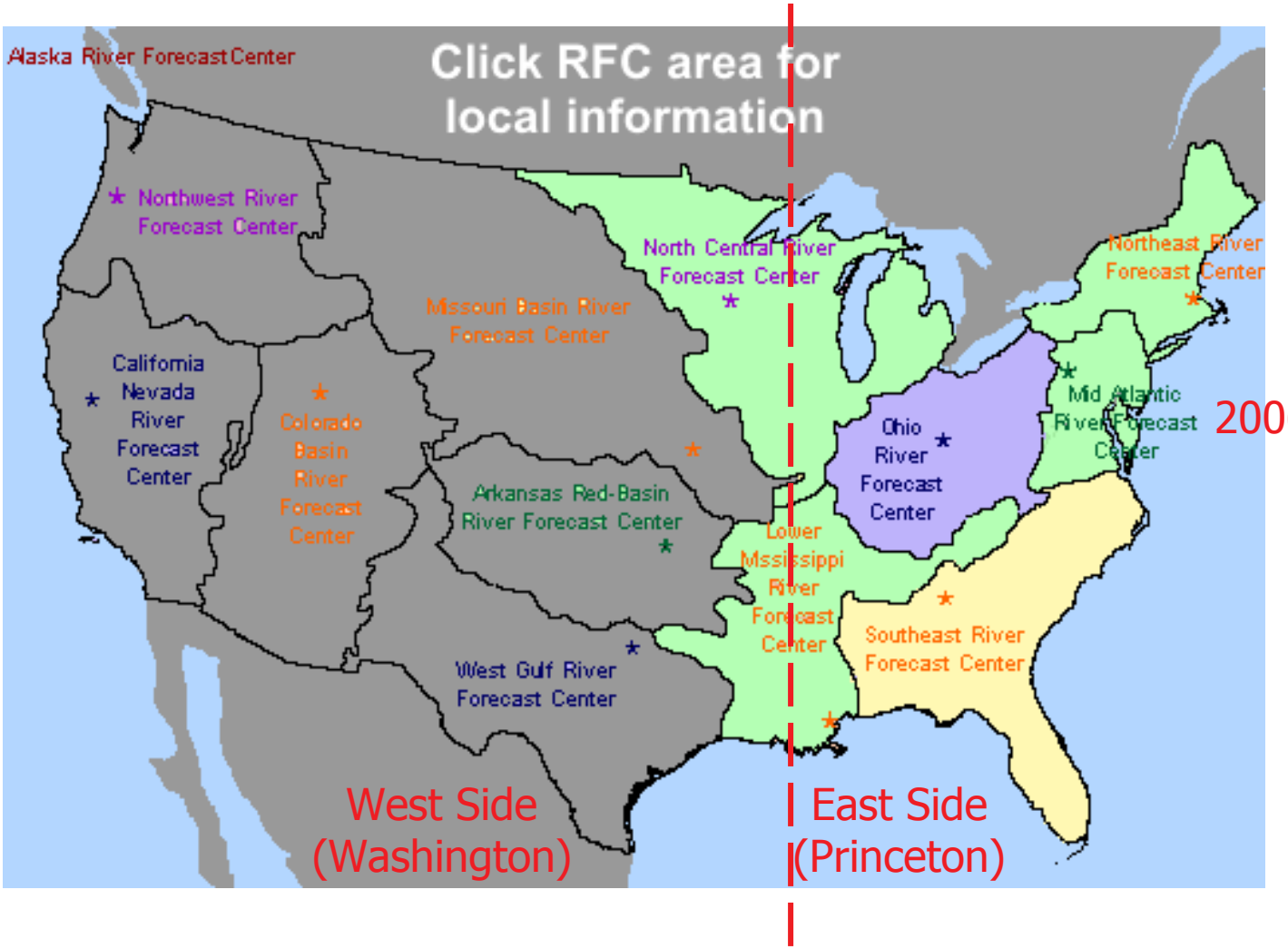
- The initial system was up and running in an operational mode from late 2003 to August 2004 when a major disk failure took place.
- The focus over the last few months, and at present, is developing a new approach to address the following problems:
  - Lack of skill in atmospheric forcing
  - Uncertainties in spatial downscaling and “weather” generator
  - Producing redundant ensembles at multiple levels.
- We are also working on improving the system code to make it more flexible for future integration with NLDAS and LIS.

Planned activities for 2005-2007

1. Expansion of the forecast area
2. Developing a multi-model seasonal forecast ensemble system, which could include observations (as a prior).

   This can be extended to the hydrological streamflow forecasting, using multi-model (LSM) Bayesian merged ensembles and multi-model, ESP-based ensembles as a prior.
3. Structuring the ensemble system within NLDAS and VIC for the southeastern U.S., and carrying out forecast evaluation.
4. Understanding the potential for seasonal predictability and forecast usefulness for the southeastern U.S.

US East-side Hydrologic Forecast System



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New bias and downscaling approach

- Merge information from multiple sources instead of relying solely on a climate model forecast
  - Climatological distribution from in-situ observations
  - Seasonal forecast from multiple climate models
  - Climate indices (current and outlook)
- Compute directly at the spatial scale that is suitable for the hydrologic application (1/8th deg or smaller), which avoids spatial downscaling.
- The hydrological ensembles are generated from the merged GCM ensemble/s and in-situ information (posterior distribution) at the local spatial scale.

Bayesian Merging of Information

Bayes Theorem

$$p(\theta \mid y) = \frac{p(\theta, y)}{p(y)} = \frac{p(\theta)\,p(y \mid \theta)}{p(y)}$$

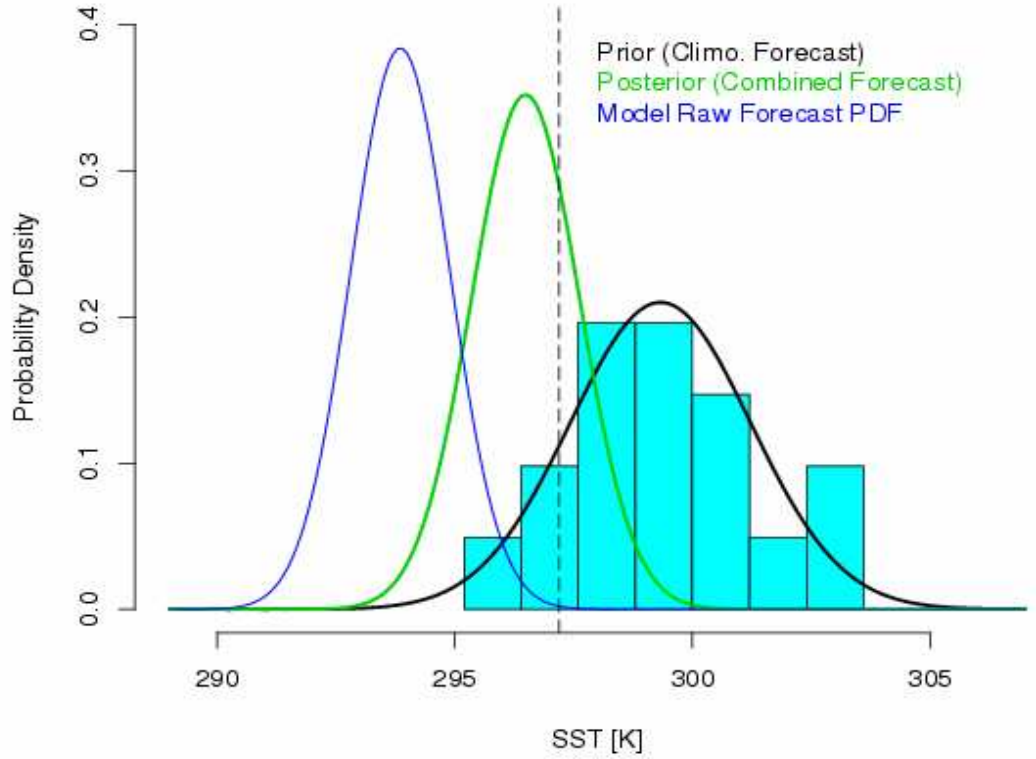
Posterior

1/8th degree scale variable

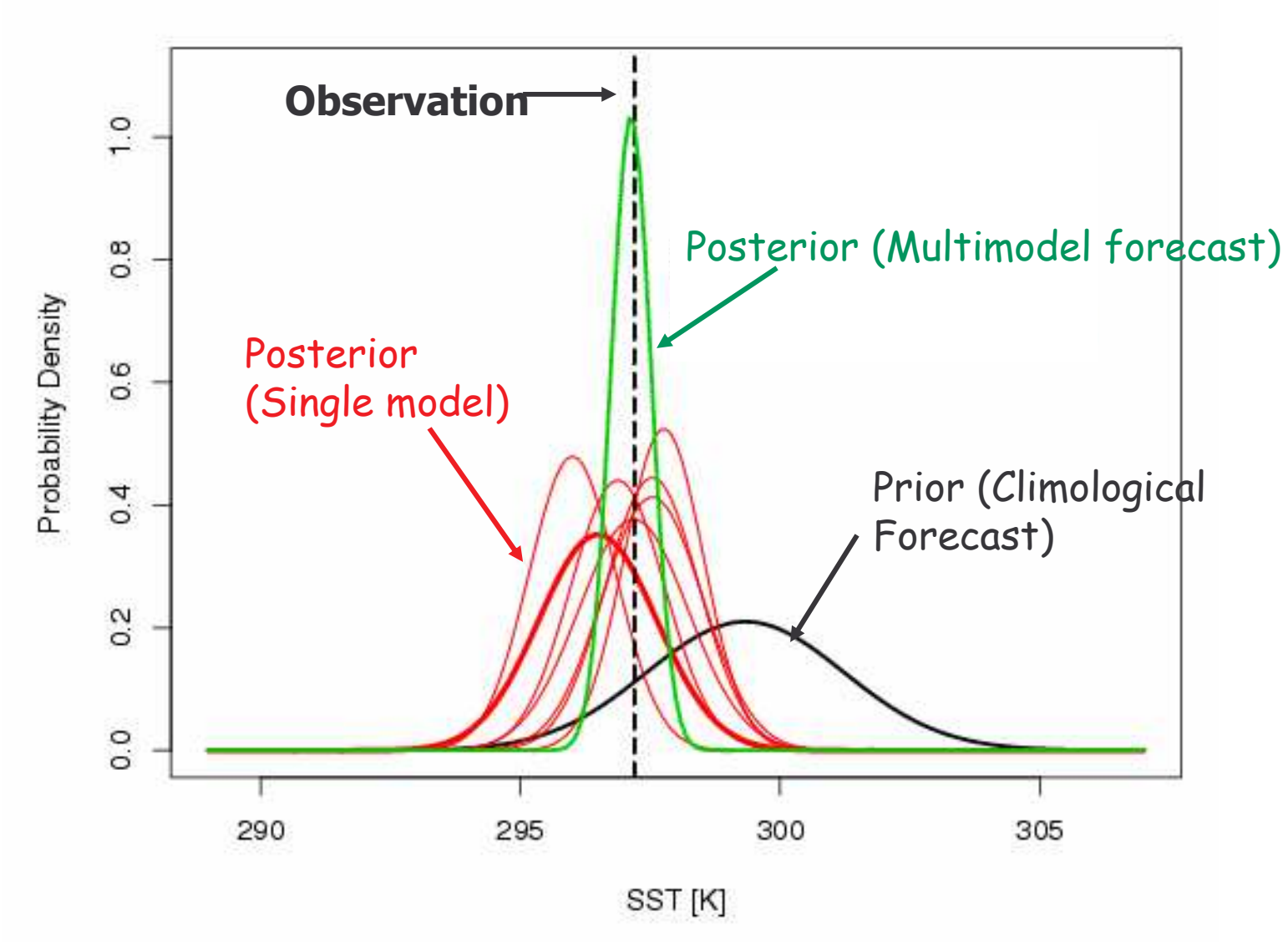
GCM-scale variable

Prior (local climatology)

Likelihood function (relates local scale to GCM scale)



Merging Multiple Model Forecast with Climatology



Example: SST Forecast

- Seasonal SST forecast from ECMWF DEMETER project
  - 7 climate models
  - 6 months forecast starting August
  - 9 ensembles from each model
  - 20 years (1980-1999)
- RMS error of all s… forecast initi…
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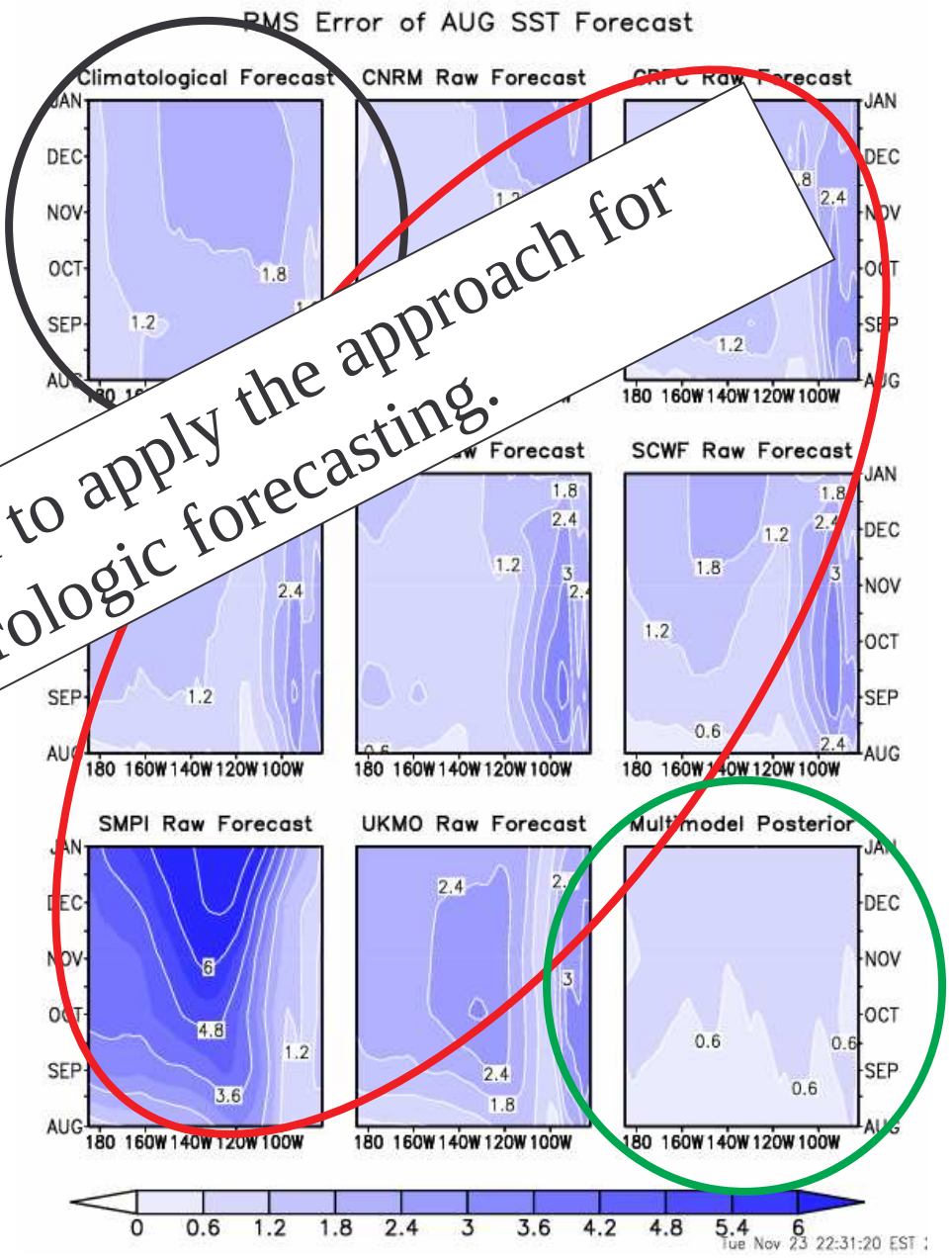
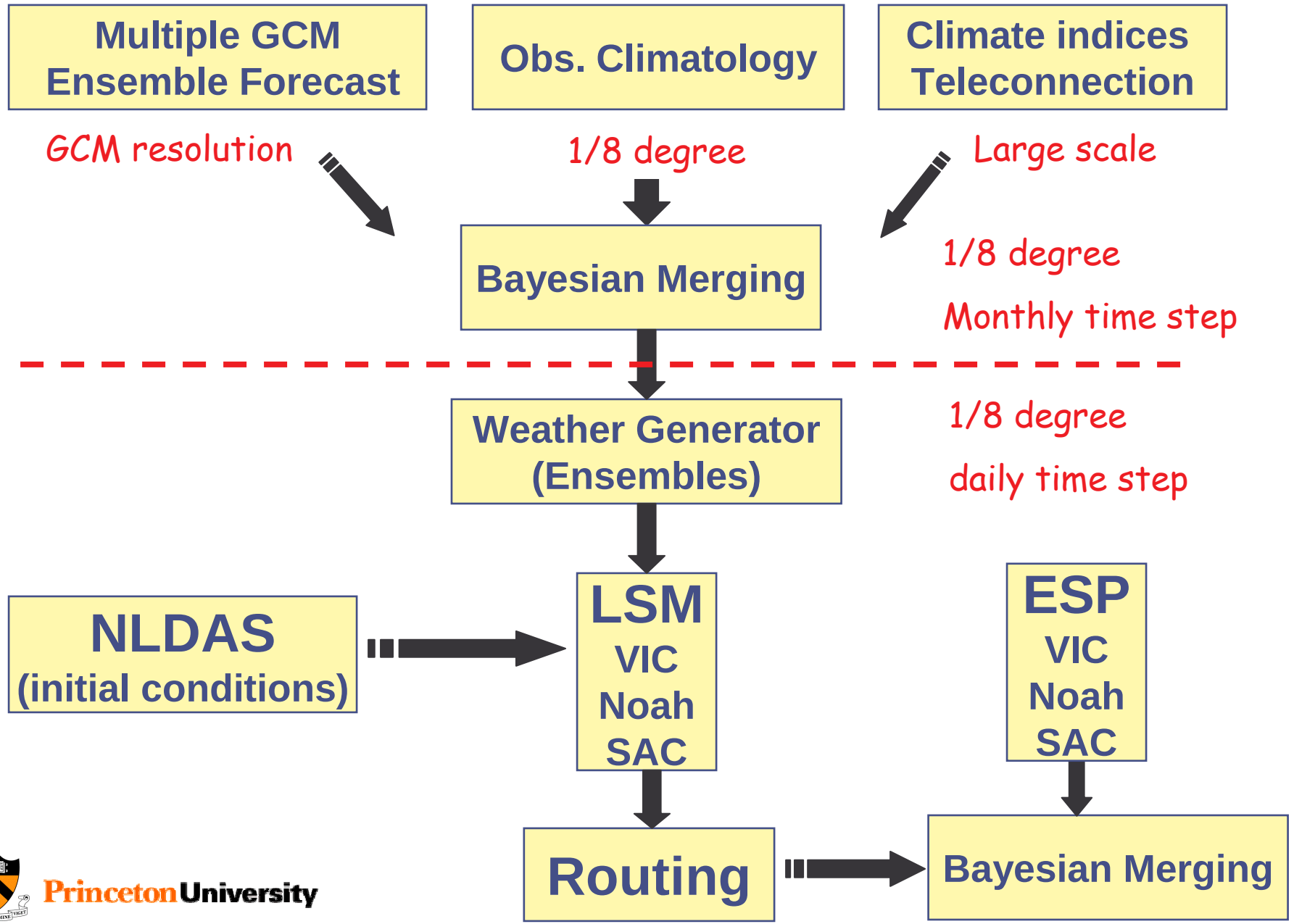
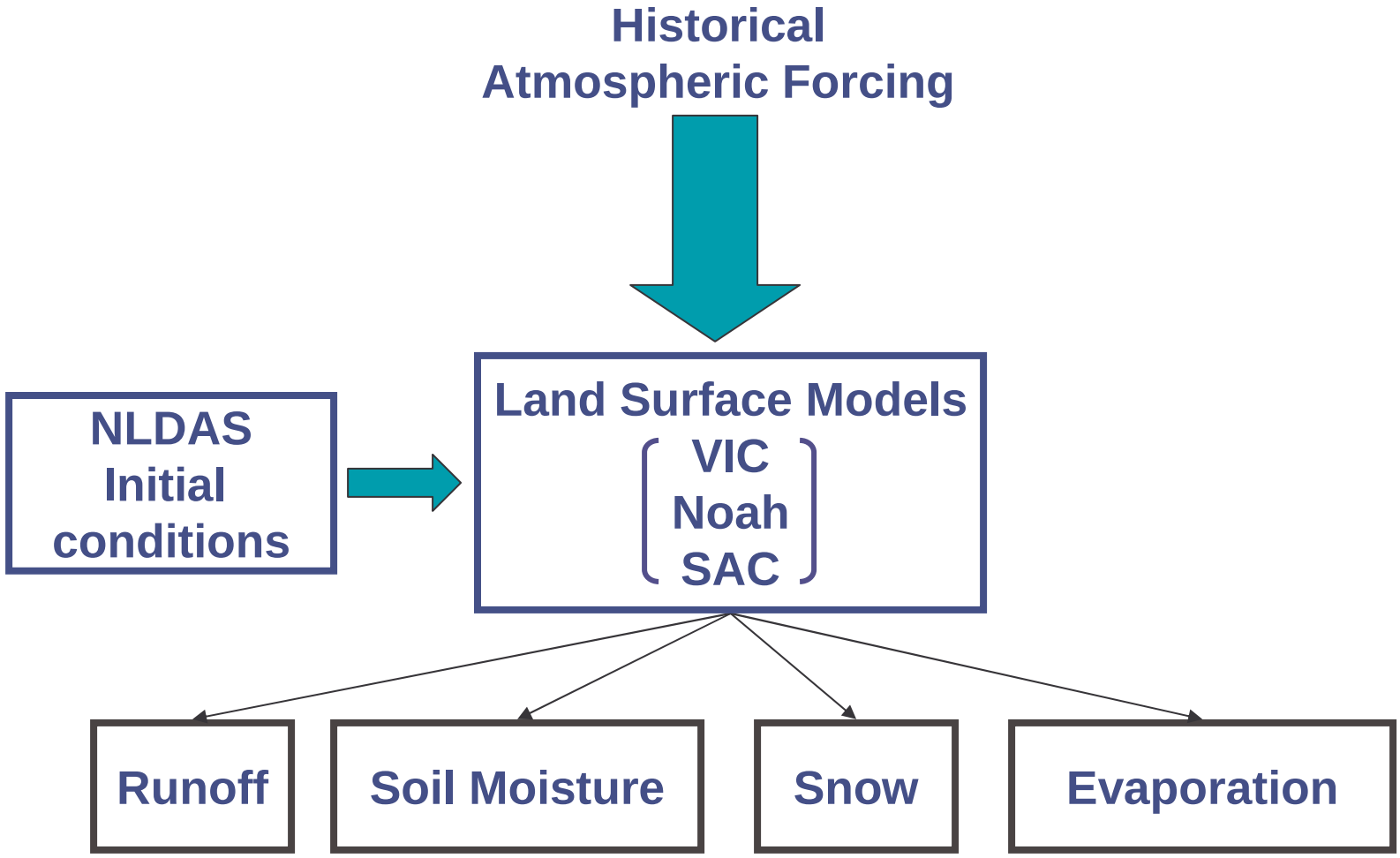
There is great potential to apply the approach for seasonal hydrologic forecasting.



Bayesian system now under development



Hydrologic Model-based ESP



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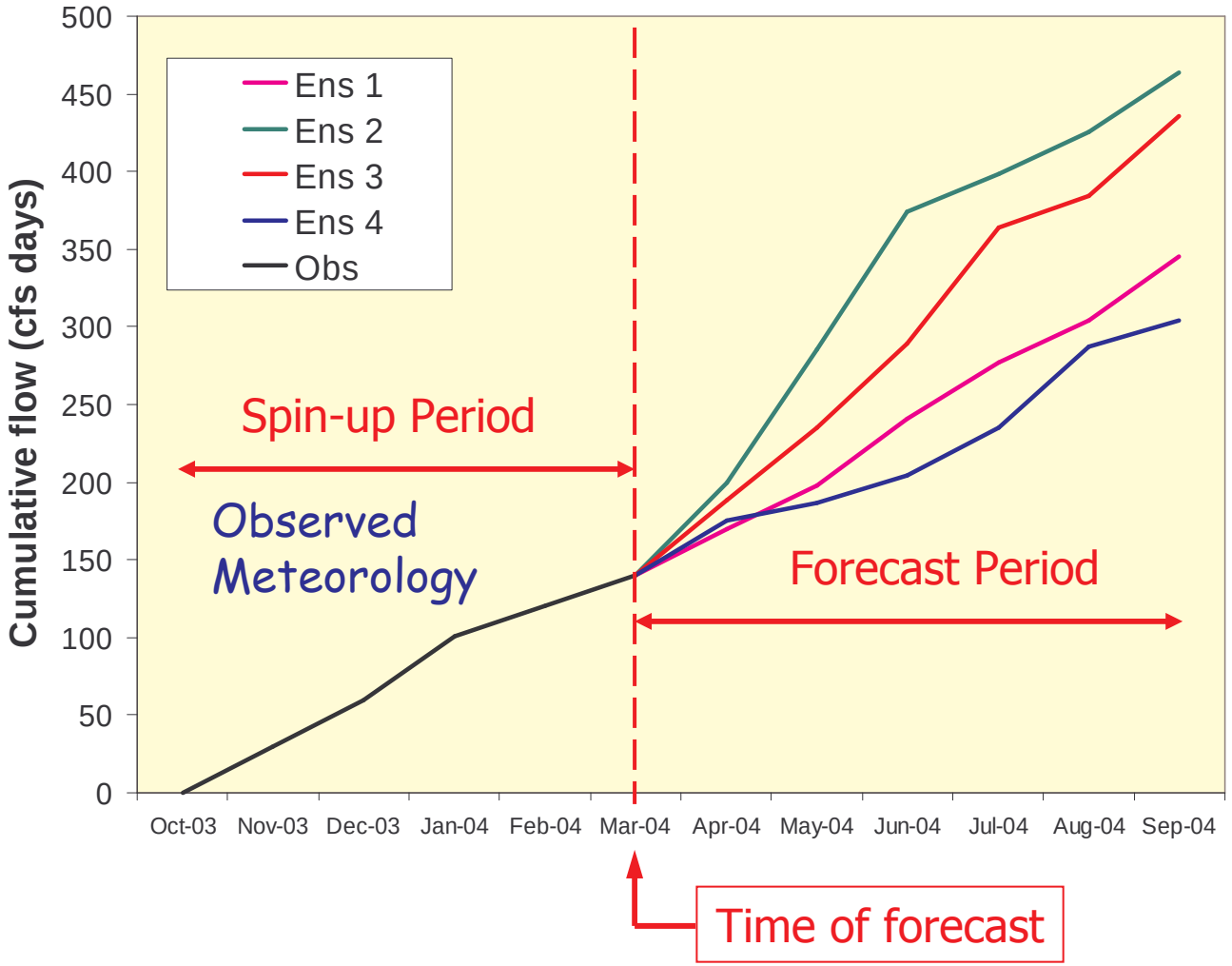

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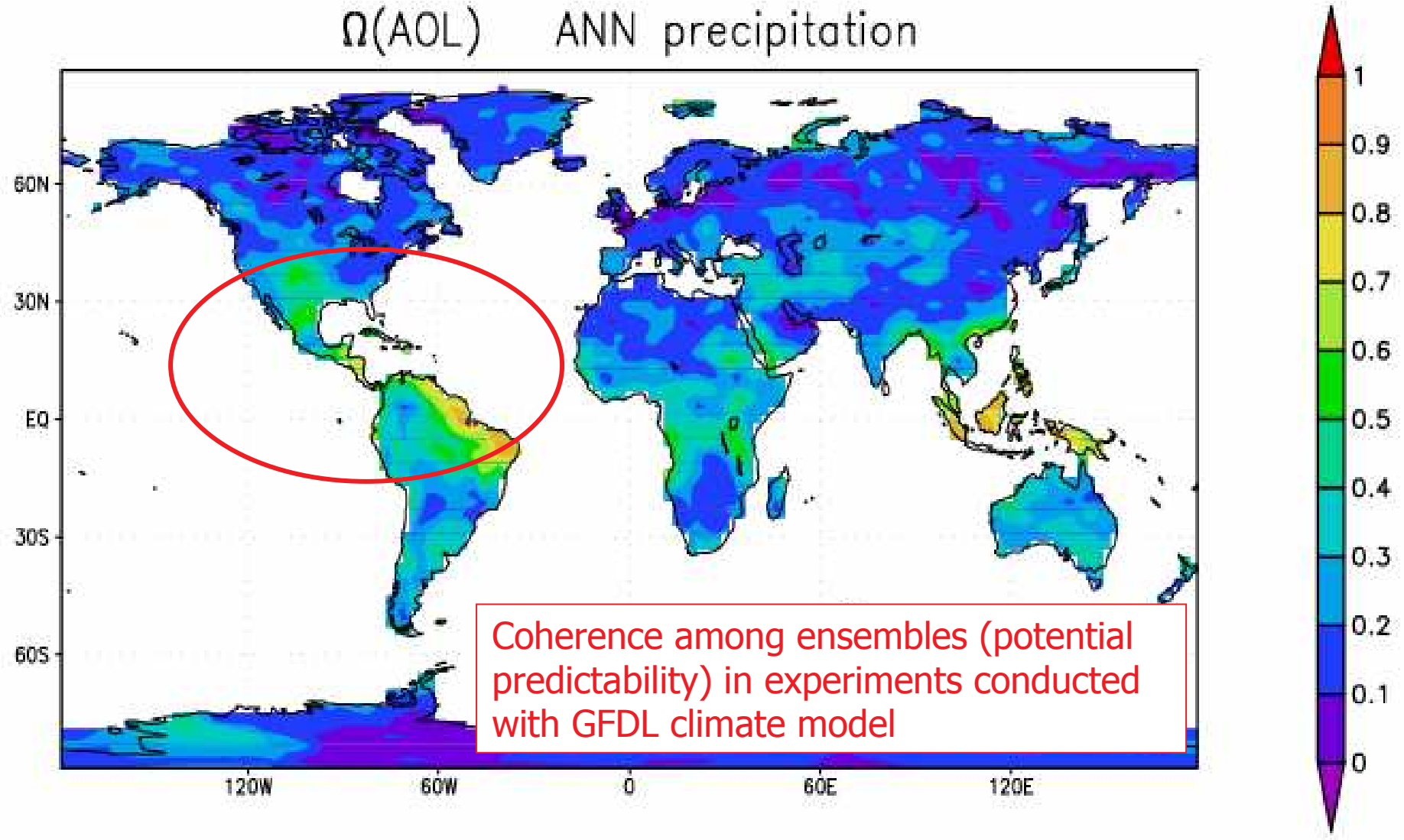
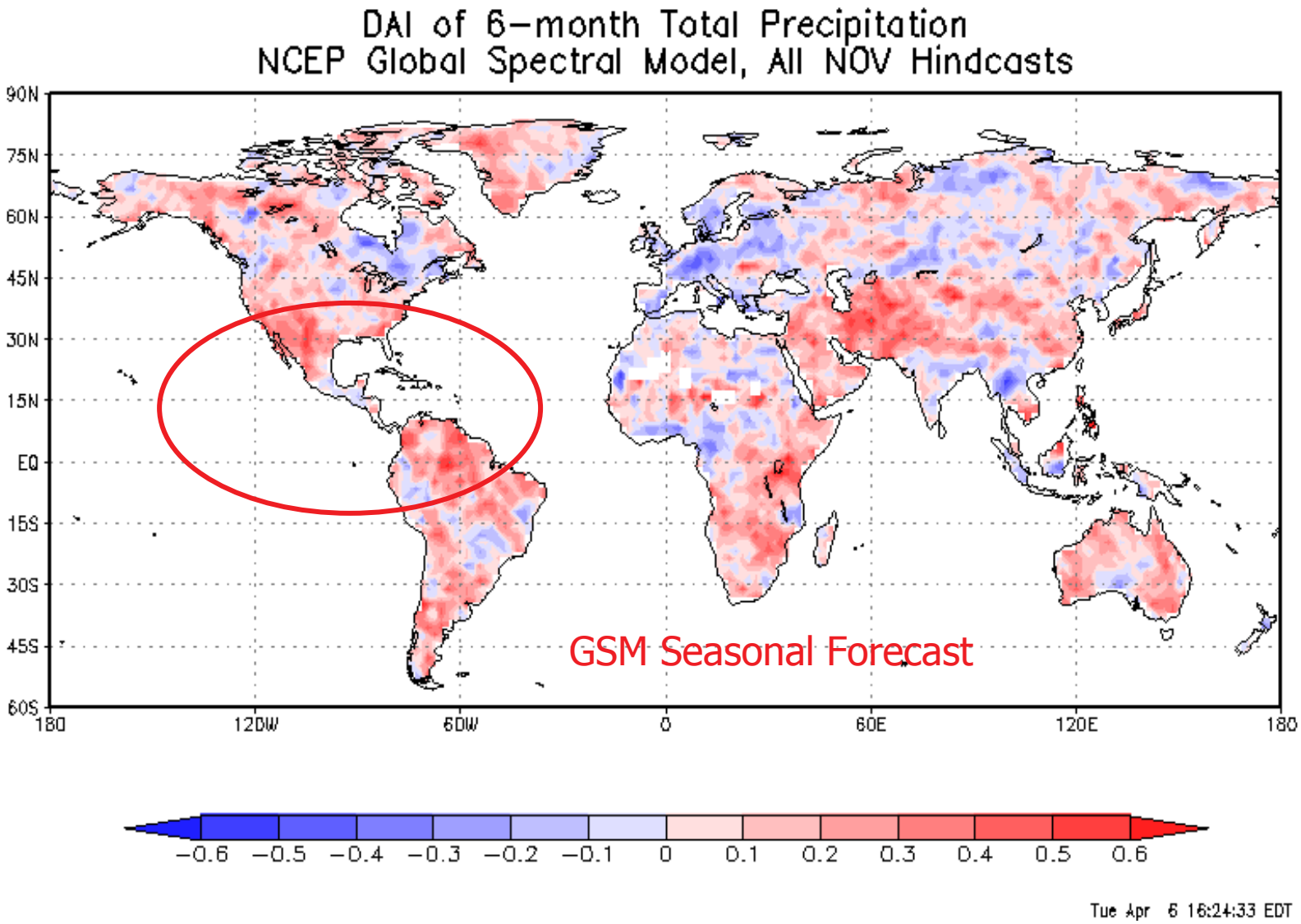
Potential Predictability of Precipitation



GSM Forecast Skill



Summary and Future Directions

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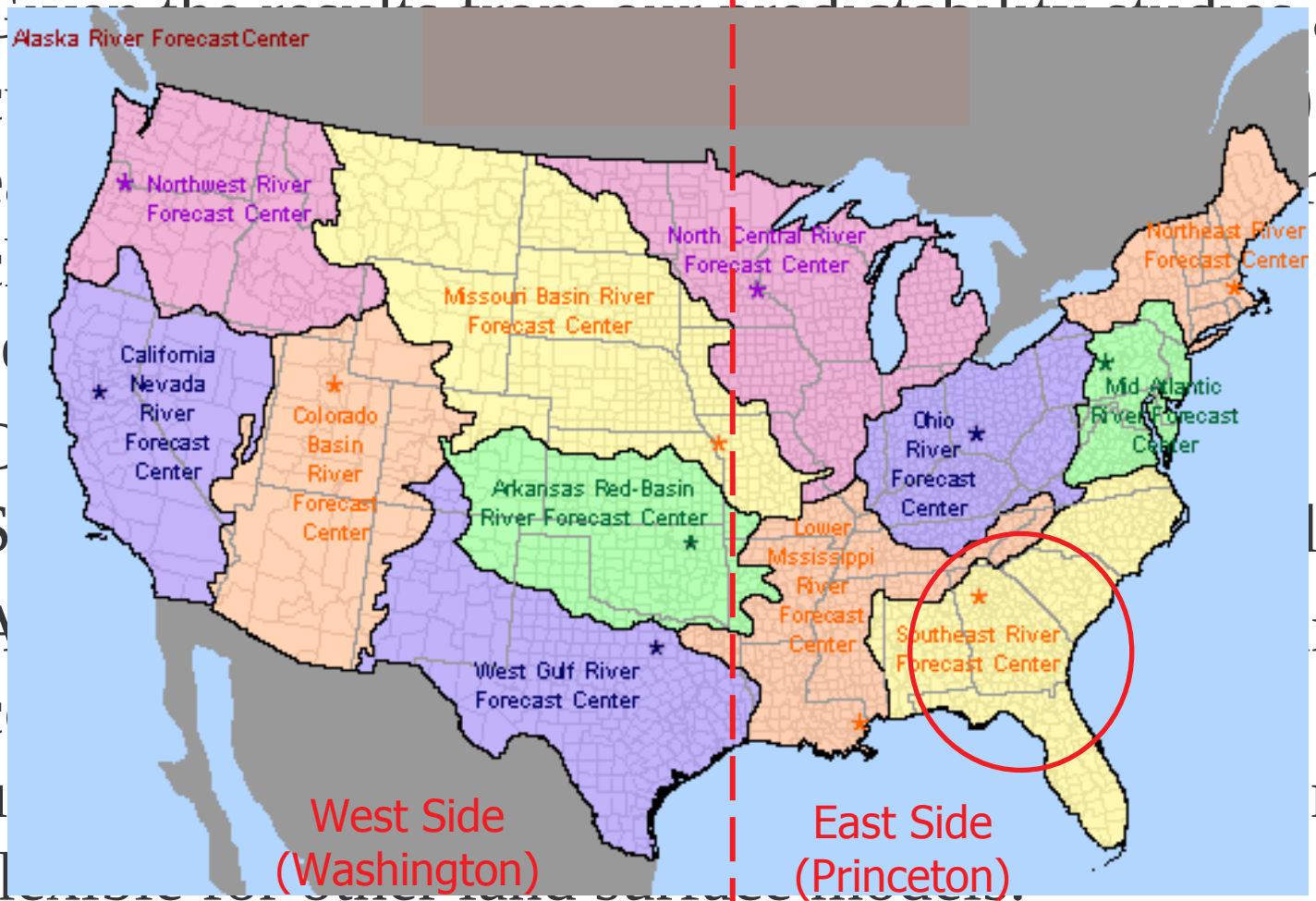

Proposed collaborations with NOAA

1. I see the seasonal hydrologic forecast system as part of the Test-bed facility (transition of research into operations).
2. Need to develop HDL/OH collaborations on evaluation of the forecasts and their useful for water management.
3. I would like to encourage the establishment of a Hydrologic Ensemble Forecasting System (HEFS) project utilizing a university-NOAA (NASA?) partnership as with NLDAS.

Thank you

Princeton University